APPENDIX C
ALUMINUM HONEYCOMB CRUSH STRENGTH CERTIFICATION

TABLE OF CONTENTS

ALUMINUM HONEYCOMB CRUSH STRENGTH CERTIFICATION

1.0 INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) developed a moving deformable barrier (MDB) for use in full-system crash testing. This included the development of a crushable face to simulate the stiffness of the front end of a striking vehicle. The main core of this barrier face assembly is to be constructed from aluminum honeycomb having a crush strength of 310 kPa ± 17 kPa (45 psi ± 2.5 psi). The specification of the barrier is given in the MDB drawing package DSL-1278 -- DSL-1287 and DSL-1290 except DSL-1282. Although, in engineering terms, strength signifies a load, since the term crush strength is commonly used by aluminum honeycomb manufacturers to signify a load per unit area, units of this measure will be kilopascal (kPa) [pounds per square inch (psi)] in this document.

This honeycomb material could potentially be manufactured by several companies, each having their own method for testing the crush strength of the material. In order to assure an equivalence between the MDB faces of the various manufacturers, a standard procedure for certifying the crush strength of the aluminum honeycomb has been established.

The MDB face assembly includes a bumper constructed of honeycomb [1690 kPa ± 103 kPa (245 psi ± 15 psi)] sandwiched between 3.2 mm (0.125") thick aluminum plates. The bumper is a flexion member and develops flexion strength based on the material properties of these front and back plates. Since the crush strength of this honeycomb is therefore not critical, the manufacturer's standard method of certifying crush strength will suffice for the bumper honeycomb.

The test contractors will obtain a copy of the certification data and procedure that the barrier face manufacturer uses to certify that the bumper honeycomb barrier meets the required crush strength of 1690 kPa ± 103 kPa (245 psi ± 15 psi).

The test contractor must obtain a copy of certification data and procedure used by the honeycomb face manufacturer to certify that the honeycomb barrier meets the 310 kPa ± 17 kPa (45 psi ± 2.5 psi).

1.0 INTRODUCTION....Continued

When barriers are delivered, the test contractor must obtain eight (8) samples that have the following dimensions [152 mm x 152 mm x 25 mm (6" x 6" x 1")] per block (as specified on page 8) from which the barrier faces were manufactured which will enable verification of the certification data supplied by barrier face manufacturer. This verification entails that the contractor possess the necessary test equipment to conduct barrier face certification testing as outlined in the following certification procedure.

2.0 OBJECTIVE

The purpose of this document is to outline a standard procedure for certifying the crush strength of the aluminum honeycomb used in constructing the main core of the MDB face assemblies. This procedure is only intended to apply to aluminum honeycomb having a nominal crush strength of 310 kPa (45 psi).

3.0 CERTIFICATION PROCEDURE

3.1 Hardware Specifications

The hardware used for certifying aluminum honeycomb must be capable of applying a sufficient load (about 13.3 kn (3,000 lb)), over at least a 17 mm (0.65") stroke. The crush rate must be constant and known (see Section 3.3). To ensure that the load is applied to the entire sample, the top and bottom crush plates must be no smaller than 165 mm by 165 mm (6.5" x 6.5"). The engaging surfaces of the crush plates must also have a roughness approximately equivalent to 60 grit sandpaper. The bottom crush plate should be marked to ensure that the applied load is centered on the sample.

Due to the construction of the aluminum honeycomb, its resistance to crush is inherently uniaxial. Off-axis loading can cause the cells to "fold-over" during certification, reducing the sample's resistance to crush, and thus its apparent crush strength. To minimize this occurrence, it is necessary that the hardware used in the certification testing be properly oriented and sufficiently rigid. Therefore, under no load, the top and bottom crush plates must be parallel, within 0.127 mm (0.005"). Also, the average angular rigidity of the crush plate assemblies (about axes normal to the direction of crush), over the range of 0 N•m to 203 N•m (0 ft-lb to 150 ft-lb) applied torque, must be at least 1017 N•m/deg (750 ft-lb/deg).

3.0 CERTIFICATION PROCEDURE....Continued

3.2 Sample Size

Much of the honeycomb's strength comes from the structure of the cells that make up the material. When these cells are cut, as is the case in preparing test samples, much of this crush strength is lost, but not all. Due to these "fringe" effects, the effective crush area is not the measured area. The percentage error between these two areas reduces as the measured area increases. It is therefore desirable to test a sample large enough such that the fringe effects do not cause large variations in crush strength but not so large as to be awkward for testing. Square pieces, 152 mm x 152 mm (6" x 6"), were found to satisfy both conditions. Samples of various thicknesses were also tested. It was found that as the thickness increased, the likelihood of the sample to buckle increased. When this occurred, the measured crush force dropped off quickly. When samples of one inch thickness were used, no noticeable buckling occurred, while allowing ample stroke for determining crush strength. Therefore, a sample thickness of one inch was selected.

Unstabilized honeycomb is to be used for these samples, and since this is difficult to cut to precise dimensions, a tolerance of ± 6 mm (± 0.25") is allowed on both the length and the width, while a tolerance of ± 1.6 mm (± 0.0625") is allowed on the thickness as shown in Figure 1, Item A. The relatively loose tolerances make it necessary to accurately measure the actual crush area of a sample. Three length measurements are taken, fringe to fringe, and recorded as L1, L2, and L3. These are to be located one-half of an inch from each end and at the middle of each sample. If these locations fall between the fringes, the measurements are to be taken from lines projected between the adjacent fringes, as shown in Figure 1, Item B. This procedure is then repeated for the width. All length and width measurements are to be taken at the centerline plane of the thickness, as shown in Figure 1, Item C. The crush area is then calculated as follows:

$$A = \frac{(L1 + L2 + L3)}{3} \text{ x } \frac{(W1 + W2 + W3)}{3}$$

3.0 CERTIFICATION PROCEDURE....Continued

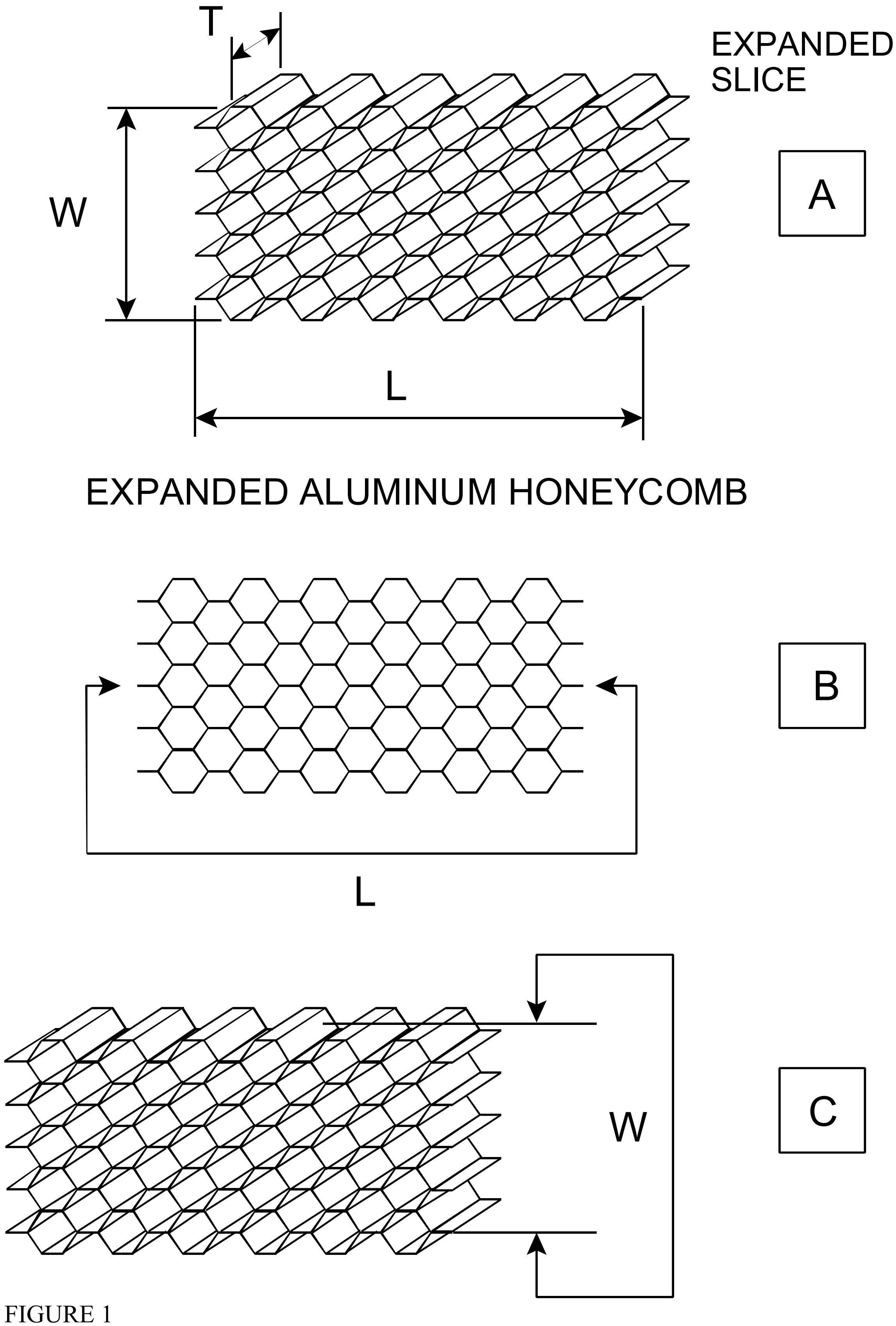


FIGURE 1

3.0 CERTIFICATION PROCEDURE....Continued

3.3 Crush Rate and Distance

The measured crush strength of aluminum honeycomb is sensitive to the crush rate used in testing. It is therefore necessary to specify a crush rate to be used in certifying crush strength. Previous testing has shown that the variation in crush strength between samples increases with increased crush rate, even if the samples are from the same block of core material.

Six samples of honeycomb were cut from the same block of core material. Three of these were crushed at a rate of 5 mm per minute (mpm) (0.2 inch per minute (ipm)) while the other three were tested at 13 mpm (0.5 ipm). Each force deflection curve was divided into three sections (to be explained in Section 3.4 - Data Analysis), giving a total of nine crush strengths for each set of samples. The standard deviation for the samples tested at 5 mpm was 2.4 kPa (0.35 psi), while it was 10.8 kPa (1.55 psi) for those done at 13 mpm (0.5 ipm). If three times the standard deviation is to be no greater than 4.7 kPa (2.5 psi (the allowable tolerance on crush strength)), then linear interpolation of the above results indicates that the crush rate should not exceed 7.6 mpm (0.3 ipm). From this, a crush rate range from 5 mpm to 7.6 mpm (0.2 ipm to 0.3 ipm) was established for this certification procedure. Another characteristic of the MDB aluminum honeycomb is that the useable crush distance is 70 percent of the initial sample thickness. Beyond this, the crush force rises quickly. To assure validity of the data, even on the thinnest sample allowed by this procedure, data from crush distances greater than 16.5 mm (0.65") will not be used. To obtain the maximum quantity of data, the minimum crush distance was specified as 16.5 mm (0.65").

3.4 Data Collection

Force versus deflection data are to be recorded for each certification test. These data may be recorded in either digital or analog form, but since digital data are required for determining the crush strengths (see Section 3.5 - Data Analysis), a means of converting analog data to digital data must be available. The rated tolerance on the load cell used to obtain this data must not be more than ± 0.5 percent, while that of the displacement transducer used must not exceed ± 1 percent. The calibration interval for each of these must be less than six months and the standard must be traceable to NIST.

3.0 CERTIFICATION PROCEDURE....Continued

One of the goals of this certification procedure was to assure uniformity in the estimation of crush forces. Uniformity can be achieved by requiring the use of digital data for the force estimations. This in turn makes it necessary to specify a digital sampling rate for these data. It was judged that a rate of 5 Hz (5 points per second) was high enough to accurately describe a continuous force/deflection curve, but not so high as to produce an unreasonably large number of data points. Therefore, the minimum sampling rate for digital data used in this certification procedure was specified to be 5 Hz.

3.5 Data Analysis

As outlined previously, digital force versus deflection data that have been collected at a minimum sampling rate of 5 Hz must be available for analysis. The data must include that part of the curve from zero to 16.5 mm (0.65") of crush.

When honeycomb is crushed, the compressive force first reaches a peak (ultimate strength) and then comes down to a fairly constant level as shown in the Figure 2 on the next page. The ultimate strength is of little interest in MDB testing since it occurs in a small interval of deflection and was not measured in MDB to load cell tests. Therefore, any data prior to 6 mm (0.25") of crush will not be used in this analysis.

This post peak data, 6.0 mm to 16.5 mm (0.25" to 0.65") of crush, will be divided into three sections or displacement intervals. The first will contain data from 6 mm to 9.6 mm (0.25" to 0.38") of crush, inclusive. The second is to span from 9.6 mm to 13.2 mm (0.38" to 0.52") of crush, exclusive, while the last includes data from 13.2 mm to 16.5 mm (0.52" to 0.65 "), inclusive. An average force, F(n), will then be calculated over each of these ranges of crush as follows:

$$F(n) = \frac{[F(n)_1 + F(n)_2 + \ldots + F(n)_l]}{l}; \quad n = 1,\ 2,\ 3$$

3.0 CERTIFICATION PROCEDURE....Continued

In the previous equation, I represents the number of data points measured in each of the three intervals. Using the area, A, measured as described in Section 3.1, the average crush strength of each segment can then be calculated as follows:

$$S(n) = \frac{F(n)}{A}; \;\; n = 1,\ 2,\ 3$$

If a honeycomb sample is to pass this certification, all three of the crush strengths calculated must meet the following specification:

293 kPa# S(n) # 327 kPa (42.5 psi # S(n) # 47.5 psi)

Figure 3 helps to illustrate the need for dividing the constant crush portion of the curve into multiple segments. If a sample produced a crush pattern similar to that of example #1, it would not be acceptable since it does not crush at a nearly constant force. Yet if a single crush strength were calculated based on the entire range of 6 mm to 16.5 mm (0.25" to 0.65"), this sample would pass the certification. A similar argument could be given for a sample which produced a crush pattern such as that of example #2. In this case, if the curve was divided into one or two segments, the sample would pass certification even though it does not display a nearly constant crush.

3.0 CERTIFICATION PROCEDURE....Continued

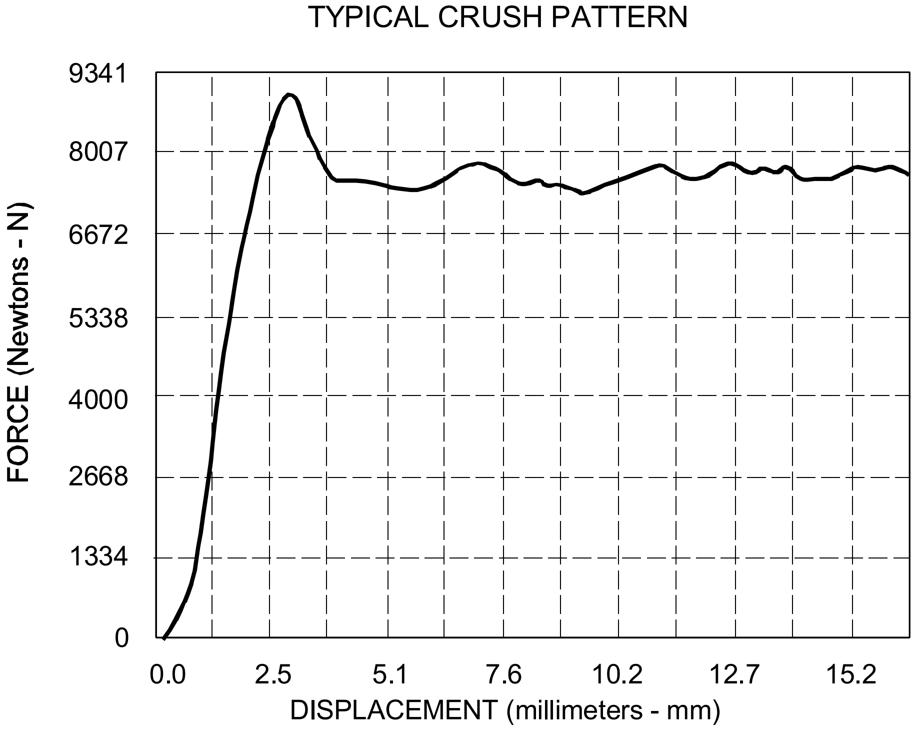


FIGURE 2

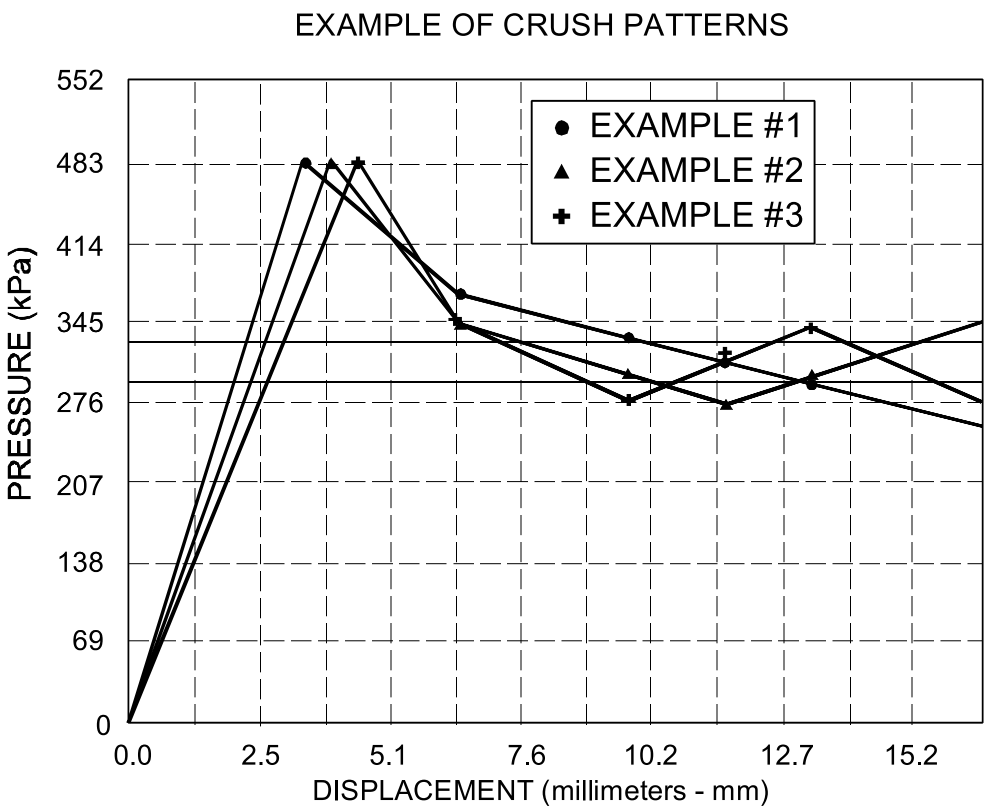


FIGURE 3

3.0 CERTIFICATION PROCEDURE....Continued

Obviously, the argument could continue to the point of requiring that every data point collected fall within the allowable range. This was impractical. Therefore it was judged that division of the post peak data into three segments would be adequate.

3.6 Block Certification Specification

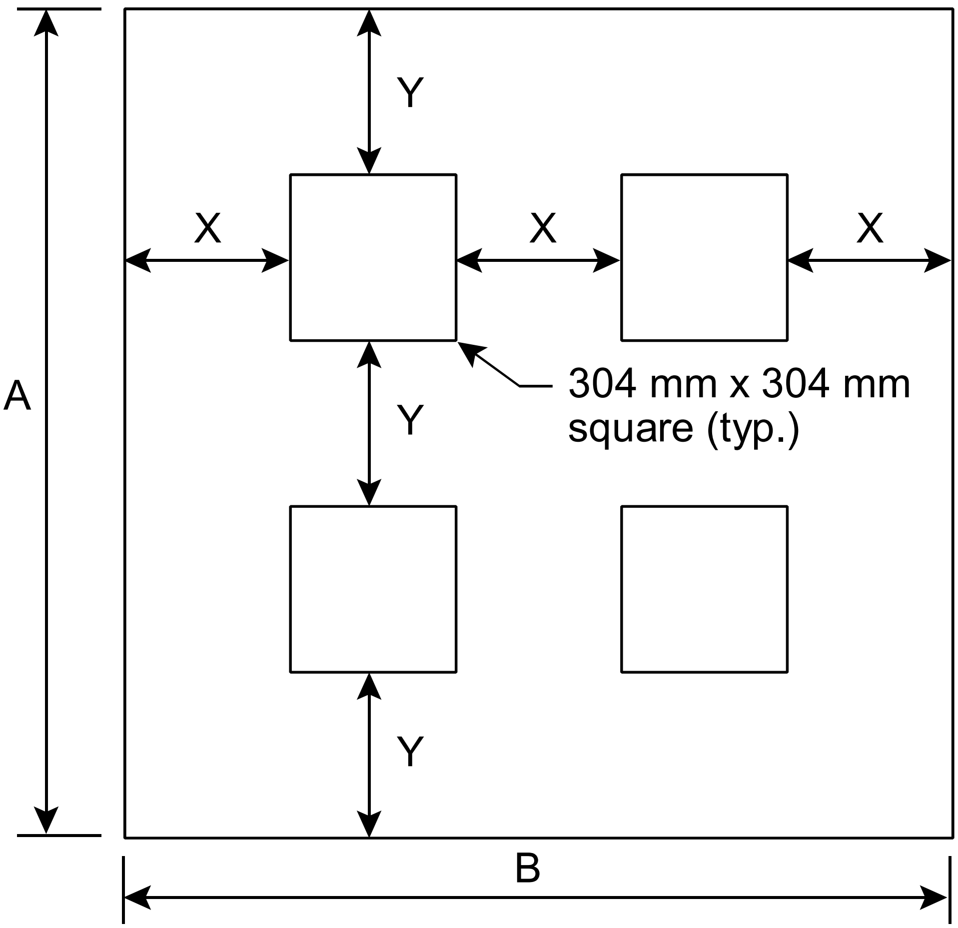
The previous discussion outlines the procedures and specifications for certifying a single sample of aluminum honeycomb. A 152 mm x 152 mm (6" by 6") sample represents only a very small portion of the entire block of honeycomb used to construct the Moving Deformable Barrier (MDB) faces. Therefore, to determine if a block has uniform properties across its entire area, 8 samples will be tested from 4 locations, evenly spaced across the block. For a block to pass certification, 7 of the 8 samples must meet the crush strength specifications outlined in the previous section.

The location of the samples depends on the size of the honeycomb block. Fist, four samples, each measuring 304 mm x 304 mm x 25 mm (12" x 12" x 1"), should be cut from the block of barrier face material. Refer to Figure 4 which describes how to locate these blocks within the material. Each of these larger samples are cut into certification size samples 152 mm x 152 mm x 25 mm (6" x 6" x 1"). The honeycomb manufacturer should certify his product based on testing two of the certification samples from each of the four locations. The other two should be made available to the customer, upon request.

3.0 CERTIFICATION PROCEDURE....Continued

HONEYCOMB SAMPLE LOCATIONS

IF A $ 914 mm: X = 1/3(B - 610 mm) & Y = 1/3(A - 610 mm)
[FOR A#B]



IF A < 914 mm: X = 1/5(B - 1220 mm) & Y = 1/2(A - 304 mm)
[FOR A#B]

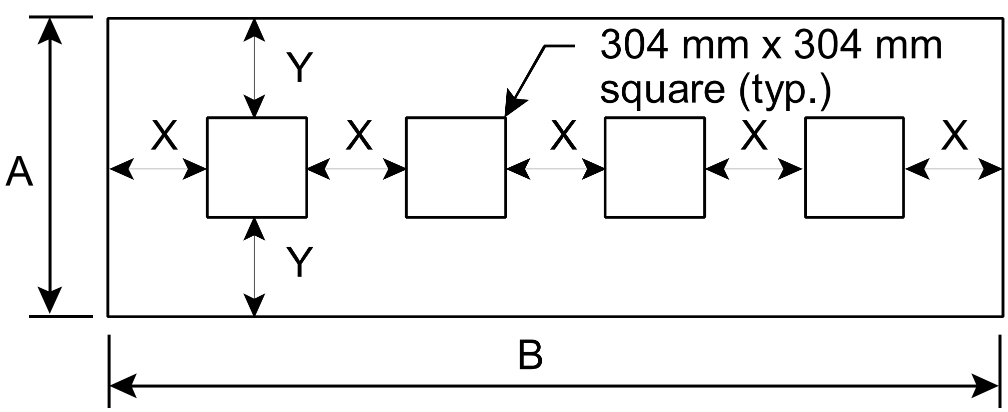


FIGURE 4

4.0 CERTIFICATION PROCEDURE SUMMARY

The following is a summary of the crush strength certification procedure outlined in the previous chapter. This procedure applies to the nominally 310 kPa (45 psi) aluminum honeycomb used in the construction of the NHTSA's MDB face assemblies.

4.1 Hardware Specifications

The testing hardware must have a capacity of applying about 13.3 kn (3,000 lb) over a stroke of at least 16.5 mm (0.65"), at a constant and known rate. The crush plates must be parallel (within 0.127 mm (0.005")), be at least 165 mm x 165 mm (6.5" x 6.5") in size, have a surface roughness approximately equivalent to 60 grit sandpaper, and be marked to ensure centering of the applied load on the sample.

The hardware used for certifying aluminum honeycomb must be capable of applying a sufficient load (about 13.3 kn (3,000 lb)), over at least a 16.5 mm (0.65") stroke. The crush rate must be constant and known (see Section 3.3). To ensure that the load is applied to the entire sample, the top and bottom crush plates must be no smaller than 165 mm by 165 mm (6.5" x 6.5"). The engaging surfaces of the crush plates must also have a roughness approximately equivalent to 60 grit sandpaper. The bottom crush plate should be marked to ensure that the applied load is centered on the sample.

Also, the crush plate assemblies must have an average angular rigidity (about axes normal to the direction of crush) of at least 1017 N•m/deg (750 ft-lb/deg), over the range of 0 N•m to 203 N•m (0 ft-lb to 150 ft-lb) applied torque.

4.2 Sample Size

Samples of unstabilized aluminum honeycomb are to be used that have the following dimensions:

Length = 152 mm ± 6 mm (6" ± 0.25")

Width = 152 mm ± 6 mm (6" ± 0.25")

Thickness = 25 mm ± 1.6 mm (1" ± 0.0625")

4.0 CERTIFICATION PROCEDURE SUMMARY....Continued

4.3 Area Measurement

The length of the sample is to be measured in three locations, 13 mm (0.5") from each end and in the middle, and recorded as L1, L2, and L3. In the same manner, the width is to be measured and recorded as W1, W2 and W3. These measurements are taken from the centerline plane of the thickness. Refer to Figures A, B and C for further illustration. The crush area is then calculated using the following formula:

$$A = \frac{(L1 + L2 + L3)}{3} \text{ x } \frac{(W1 + W2 + W3)}{3}$$

4.4 Crush Rate and Distance

The sample is to be crushed at a rate not less than 5 mpm (0.2 ipm) and not more than 7.6 mpm (0.3 ipm). The sample is to be crushed a minimum of 16.5 mm (0.65").

4.5 Data Collection

Force versus deflection data are to be collected in either analog or digital form for each sample tested. If analog data are collected, a means of converting this to digital data must be available. All digital data must be collected at a rate of no less than 5 Hz (5 points per second).

4.6 Crush Strength Determination

Ignore all data prior to 6 mm (0.25") of crush and after 16.5 mm (0.65 inch) of crush. Divide the remaining data into three sections or displacement intervals (n = l, 2, 3) as follows:

A. 6 mm to 9.6 mm (0.25" to 0.38"), inclusive

B. 9.6 mm to 13.2 mm (0.38" to 0.52"), exclusive

C. 13.2 mm to 16.5 mm (0.52" to 0.65"), inclusive

4.0 CERTIFICATION PROCEDURE SUMMARY....Continued

Find the average force for each section as follows:

$$F(n) = \frac{[F(n)_1 + F(n)_2 + \ldots + F(n)_l]}{l}; \; n = 1, 2, 3$$

In this equation, "l" represents the number of data points measured in each of the three intervals. Calculate the average crush strength of each section as follows:

$$S(n) = \frac{F(n)}{A}; \; n = 1, 2, 3$$

4.7 Sample Crush Strength Specification

For a honeycomb sample to pass this certification, the following condition must be met:

293 kPa# S(n) # 327 kPa (42.5 psi # S(n) # 47.5 psi)
n = 1,2,3

4.8 Block Crush Strength Specification

Eight (8) samples are to be tested from 4 locations, evenly spaced across the block. For a block to pass certification, 7 of the 8 samples must meet the crush strength specification outlined in the previous section.

4.0 CERTIFICATION PROCEDURE SUMMARY....Continued

4.9 Information Required by COTR

The following information is to be forwarded to the COTR, for each order placed, prior to delivery of the finished product:

A. Sample Identification. Give all information necessary to trace the sample back to its original block of core material.

B. Certification Date

C. Values for L1, L2, L3, W1, W2, W3, and thickness

D. Calculated Area, A

E. Average Forces, F(1), F(2), and F(3)

F. Average Crush Strengths, S(1), S(2), and S(3)

G. Force versus Deflection plot of the sample, with scaled axes